starting point indicated by the position P0 to the end point indicated by the position Q0. The angle formed by the central axis of the tool and a perpendicular line (straight line perpendicular to the center axial line 10c) at the starting point P0 is designated as θ1, and the angle formed by the central axis of the tool and this perpendicular line at the end point Q0 is designated as θ2. The (X coordinate, Z coordinate) of the starting point P0 are designated as (xp0, zp0), and the (X coordinate, Z coordinate) of the end point Q0 are designated as (xq0, zq0). The respective coordinate values of the starting point P0 and end point Q0 are determined using the following equations.

$$xp0 = a + e0 \cdot \cos(\theta 1)$$

$$zp0 = zm - e0 \cdot \sin(\theta 1)$$

$$xq0 = a + e0 \cdot \cos(\theta 2)$$

$$zq0 = zm + e0 \cdot \sin(\theta 2)$$

Accordingly, it is sufficient if the system is controlled so that the center of the turning axis 73 describes a circular arc (a clockwise circular arc in this case) which passes through the starting point P0 and end point Q0 determined by the above equations, and whose radius is the distance e0. Furthermore, in the NC machining program of a lathe or turning center, the X coordinate is ordinarily indicated as a diameter; here, however, the value of the X coordinate is indicated as the value of the distance itself in order to

simplify the description. The value of the X axis here needs to be doubled in order to get the value that indicates a diameter.

The X axis and Z axis are controlled so that the center of the turning axis 73 of the tool rest main body 71 moves over a circular-arc track which passes through the starting point P0 and end point Q0, and which has a radius of e0. Furthermore, in synchronization with this, the turning tool rest 72 is caused to perform a B axis turning motion about the turning axis 73 from the rotational angle corresponding to the angle θ1 to the rotational angle corresponding to the angle θ2. Moreover, the cutting edge of the tool is caused to perform a motion along the helical groove of the workpiece 10 by causing the workpiece 10 to perform a C axis rotational motion about the center axial line 10c concurrently and synchronously with the abovementioned motions.

Next, in Fig. 9, in order to cause the tool to cut into the helical groove, the distance g1 between the tip end of the cutting edge of the tool and center axial line 10c of the workpiece 10 in the closest state is reduced to a value that is smaller than the distance g0 in Fig. 8. Specifically, the distance g1 is selected so that this distance is smaller than the radius of the workpiece 10. In this case, the radius r1 of the circular arc described by the tip end of the cutting edge of the tool is larger than the radius r0 in Fig. 8, and the radius e1 of the circular arc described by the center of

the turning axis 73 is smaller than the radius e0 in Fig. 8. From Fig. 9, the distance e1 is determined using the following equation.

$$e1 = i + h - r1$$

The turning axis 73 of the turning tool rest 72 is controlled so that this axis performs a circular-arc motion from the starting point indicated by the position P1 to the end point indicated by the position Q1. The B axis turning motion of the turning tool rest 72 about the turning axis 73 has the same starting angle and ending angle as in the case of Fig. 8. The (X coordinate, Z coordinate) of the starting point P1 are designated as (xp1, zp1), and the (X coordinate, Z coordinate) of the end point Q1 are designated as (xq1, zq1). The respective coordinate values of the starting point P1 and end point Q1 are determined using the following equations.

$$xp1 = a + e1 \cdot \cos(\theta 1)$$

$$zp1 = zm - e1 \cdot \sin(\theta 1)$$

$$xq1 = a + e1 \cdot \cos(\theta 2)$$

$$zq1 = zm + e1 \cdot \sin(\theta 2)$$

Thus, the circular-arc track that is to be described by the center of the turning axis 73 of the tool rest main body 71 is determined from the radius r1 of the circular arc described by the tip end of the cutting edge of the tool (or the distance g1). The X axis and Z axis are controlled so that the center of the turning axis 73 of the tool rest main

body 71 is caused to move along a circular-arc track with a radius of e1 that passes through the starting point P1 and end point Q1; furthermore, in synchronization with this motion, the turning tool rest 72 is caused to perform a B axis turning motion about the turning axis 73 from the rotational angle corresponding to the angle $\theta 1$ to the rotational angle corresponding to the angle $\theta 2$. Moreover, the cutting edge of the tool is caused to move along the helical groove of the workpiece 10 by causing the workpiece 10 to perform a C axis rotational motion about the center axial line 10c concurrently and synchronously with the abovementioned motions, so that finishing machining of the helical groove is performed.

Next, in Fig. 10, in order to cause the tool to cut further into the helical groove, the distance g2 between the tip end of the cutting edge of the tool and the center axial line 10c of the workpiece 10 in the closest state is reduced to a value that is smaller than the distance g1 in Fig. 9. In this case, the radius r2 of the circular arc described by the tip end of the cutting edge of the tool is larger than the radius r1 in Fig. 9, and the radius e2 of the circular arc described by the center of the turning axis 73 is smaller than the radius e1 in Fig. 9. From Fig. 10, the distance e2 is determined using the following equation.

$$e2 = i + h - r2$$

The system is controlled so that the turning axis 73 of the turning tool rest 72 performs a circular-arc motion from the starting point indicated by the position P2 to the end point indicated by the position Q2. The B axis turning motion of the turning tool rest 72 about the turning axis 73 has the same starting angle and ending angle as in the cases shown in Figs. 8 and 9. The (X coordinate, Z coordinate) of the starting point P2 are designated as (xp2, zp2), and the (X coordinate, Z coordinate) of the end point Q2 are designated as (xq2, zq2). The respective coordinate values of the starting point P2 and end point Q2 are determined using the following equations.

$$xp2 = a + e2 \cdot \cos(\theta 1)$$

$$zp2 = zm - e2 \cdot \sin(\theta 1)$$

$$xq2 = a + e2 \cdot \cos(\theta 2)$$

$$zq2 = zm + e2 \cdot \sin(\theta 2)$$

Thus, the circular-arc track that is to be described by the center of the turning axis 73 of the tool rest main body 71 is determined from the radius r2 of the circular arc described by the tip end of the cutting edge of the tool (or the distance g2). The X axis and Z axis are controlled so that the center of the turning axis 73 of the tool rest main body 71 is caused to move along a circular-arc track with a radius of e2 that passes through the starting point P2 and end point Q2. In synchronization with this motion, the turning

tool rest 72 is caused to perform a B axis turning motion about the turning axis 73 from the rotational angle corresponding to the angle θ1 to the rotational angle corresponding to the angle θ2. Furthermore, the cutting edge of the tool is caused to move along the helical groove of the workpiece 10 by causing the workpiece 10 to perform a C axis rotational motion about the center axial line 10c concurrently and synchronously with the abovementioned motions, so that finishing machining of the helical groove is performed.

Thus, as is shown in Figs. 8 through 10, the finishing machining of the helical groove is completed by repeating machining a plurality of times with the amount by which the tool cuts into the helical groove being increased in stages. As was indicated in the above description, the circular-arc track that is described by the center of the turning axis 73 of the tool rest main body 71 at each amount of cutting is determined from the radius of the circular arc described by the tip end of the cutting edge of the tool, or the distance between the tip end of the cutting edge of the tool and the center axial line 10c of the workpiece 10 in the closest state.

Fig. 11 is a flow chart which shows the procedure of the finishing machining of the helical groove. In this flow chart, the radius of the circular arc described by the tip end of the cutting edge of the tool is indicated as the cutting edge rotational radius r, the radius of the circular-arc track that

is to be described by the center of the turning axis 73 of the tool rest main body 71 is indicated as the turning axis rotational radius e, and the coordinates of the starting point P and end point Q of the circular-arc track are indicated as P(xp, zp) and Q(xq, zq). Furthermore, the data used to specify the position of the turning center M is preset.

First, in step 101, the X and Z axes of the tool rest main body 71 are controlled so that the tool rest main body 71 is moved into the waiting position. Next, in step 102, the turning axis rotational radius e is calculated from the cutting edge rotational radius r. Furthermore, as was indicated in the description of Fig. 8, the turning axis rotational radius e may also be calculated from the distance g between the tip end of the cutting edge of the tool and the center axial line of the workpiece in the closest state. Next, in step 103, the X and Z axis coordinates of the starting point P(xp, zp) and end point Q(xq, zq) of the circular-arc track that is to be described by the center of the turning axis 73 of the tool rest main body 71 are calculated from the turning axis rotational radius e and angles θ1 and θ2.

Then, in step 104, the turning tool rest 72 is caused to perform a B axis turning motion about the turning axis 73, and the rotational angle is taken as the rotational angle corresponding to the angle θ1. Furthermore, the Z axis of the tool rest main body 71 is controlled so that the tool rest

main body 71 is moved into the starting point position zp. Moreover, the X axis of the tool rest main body 71 is controlled so that the tool rest main body 71 is moved into the starting position xp.

Next, in step 105, the following X and Z axis control, B axis control and C axis control are performed in synchronization. The X and Z axis control constitute a circular-arc interpolating action that causes the center of the turning axis 73 of the tool rest main body 71 to move along a circular arc with a radius of e from the staring point P to the end point Q. The B axis control constitutes a rotational action that causes the turning tool rest 72 to rotate about the turning axis 73 from the rotational angle corresponding to the angle $\theta 1$ to the rotational angle corresponding to the angle $\theta 2$. The C axis control constitutes a C axis rotational action that causes the workpiece 10 to rotate about the center axial line 10c from a specified starting angle to a specified ending angle. The starting angle and ending angle of the C axis rotation are set in accordance with the shape of the helical groove. The X and Z axis control, B axis control and C axis control of this step 105 are synchronous actions, and these respective axial controls are performed concurrently and in synchronization. Specifically, all of these axial operations are controlled so as to start at the same time and end at the same time.

Then, in step 106, the X and Z axes of the tool rest main body 71 are controlled so that the tool rest main body 71 is moved into the waiting position. Next, in step 107, a judgement is made as to whether or not the cutting edge rotational radius r has reached the final radius. Here, the "final radius" refers to the final cutting edge rotational radius that is reached when the finishing machining of the helical groove is performed with the cutting edge rotational radius successively increased. If the cutting edge rotational radius r has reached the final radius, the entire finishing machining procedure is ended; if the cutting edge rotational radius has not reached the final radius, the procedure proceeds to step 108. In step 108, the cutting edge rotational radius is increased by a specified amount Δr. Then, the procedure returns to step 102, and the steps from step 102 on are repeated. Specifically, finishing machining is performed with the cutting edge rotational radius successively increased in a stepwise manner, i. e., with the amount of cutting increased in a stepwise manner, until the cutting edge rotational radius r reaches the final radius.

Fig. 12 is a diagram which shows the shape of the plate-form bite 77. Fig. 12 (a) is a front view of the plate-form bite 77, and Fig. 12 (b) is a side view of the plate-form bite 77. A plate-form tip 77t constituting a cutting edge is fastened to the tip end portion of the plate-form bite 77. The front surface of the tip 77t is a cutting surface. The

tip 77t is attached so that the tip shows left-right symmetry with respect to the center axial line T of the tool as seen from the front, and so that the cutting surface passes through the center axial line T.

The shape of the cutting surface of the tip 77t is the cross-sectional shape of the groove that is being machined. Accordingly, if the cutting surface of the tip 77t is formed with a shape that spreads out on the tip end side as is shown in Fig. 12 (c), a helical groove with a cross-sectional shape (such as that shown in Fig. 12 (d)) that corresponds to this cutting surface shape can also be machined. Furthermore, helical grooves with other arbitrary cross-sectional shapes can also be machined by altering the cutting surface shape of the tip 77t.

Fig. 13 is a diagram which shows the construction of another configuration of the turning tool rest 72c. This turning tool rest 72c differs from the turning tool rest 72 shown in Fig. 1 in that the plate-form bite 77 is attached in fixed manner. Specifically, the plate-form bite 77 cannot be automatically replaced by the automatic tool changer 8; however, the plate-form bite 77 can be detachably attached to the turning tool rest 72c in a state in which the supporting rigidity is large. In Fig. 13 (a), an end mill 78 which is a rotating tool is mounted in the tool mounting part which allows automatic tool replacement.

Here, the center axial line Ta of the end mill 78 and the center axial line Tb of the plate-form bite 77 both pass through the center of the turning axis 73, and intersect at a specified angle. This is done in order to prevent interference between the plate-form bite 77 and the workpiece during machining performed by the end mill 78. In this case of rough machining of the helical groove, the end mill 78 is mounted in the tool mounting part, and this machining is performed by the end mill 78, as is shown in Fig. 13 (a).

In the case of the finishing machining of the helical groove, the end mill 78 is removed from the tool mounting part, a dummy tool 80 is mounted, and this machining is performed by the plate-form bite 77, as is shown in Fig. 13 (b). The dummy tool 80 covers the tool mounting part, and is used to prevent foreign matter such as cutting debris, coolant and the like from entering the interior of the tool mounting part. The procedure of the finishing machining is performed in the same manner as that described in Figs. 8 through 11.

Fig. 14 is a diagram which shows the procedure whereby a helical groove with a groove width that differs from the width dimension of the blade part of the plate-form bite is machined. First, as is shown in Fig. 14 (a), one side wall 13 of the helical groove 11 is machined by the plate-form bite 77. This is accomplished by causing the plate-form bite 77 to turn through a specified angle and causing the workpiece 10 to rotate through a specified angle as described in Figs. 8

through 10. Next, the phase relationship of the turning of the plate-form bite 77 and the rotation of the workpiece 10 is slightly shifted, and the other side wall 14 of the helical groove 11 is machined by the plate-form bite 77 as shown in Fig. 14 (b).

The phase between the turning of the plate-form bite 77 and the rotation of the workpiece 10 can be shifted by shifting the positions of the starting point P and end point Q of the circular-arc track that is to be described by the center of the turning axis 73 of the tool rest main body 71. Specifically, the positions of the angles θ1 and θ2 are shifted. Alternatively, the starting angle and ending angle of the rotation of the workpiece 10 may be shifted. By performing machining as shown in Fig. 14 (a) and Fig. 14 (b), it is possible to machine a helical groove which has a groove width that is wider than the width dimension of the blade part of the tip 77t.

In the present invention, as was described above, machining can easily be performed even in cases where helical grooves or the like with a complex shape are machined in the workpiece, by performing a synchronous operation in which a circular arc interpolating action, B axis turning action and C axis rotational action (provided in a common NC device) are combined. Furthermore, in regard to the shape of the helical groove as well, the machining of diverse shapes with high all-purpose utility can also be accomplished. Moreover, the

machining of other portions of the workpiece can also be continuously performed before or after the machining of such a helical groove, so that the machining efficiency of the workpiece can be greatly improved.

[Merits of the Invention]

Since the present invention is constructed as described above, the present invention possesses the following merits.

The turning tool rest can be caused to perform a turning motion about an arbitrary position by concurrently and synchronously causing a turning motion and circular-arc motion of the turning tool rest, so that the machining of complex shapes in the workpiece can easily be performed.

The machining of helical grooves with complex shapes in the workpiece can easily be accomplished by concurrently and synchronously causing a turning motion and circular-arc motion of the turning tool rest and a rotational motion of the workpiece. In regard to the shape of such helical grooves as well, the machining of diverse shapes with high all-purpose utility can be accomplished. Furthermore, the machining of other portions of the workpiece can also be continuously performed before or after the machining of such a helical groove, so that the machining efficiency of the workpiece can be greatly improved.